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Biofuels and sustainability in Africa

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ABSTRACT

The combined effects of climate change, the continued volatility of fuel prices, the recent food crisis and global economic turbulence have triggered a sense of urgency among policymakers, industries and development practitioners to find sustainable and viable solutions in the area of biofuels. This sense of urgency is reflected in the rapid expansion of global biofuels production and markets over the past few years. Biofuels development offers developing countries some prospect of self-reliant energy supplies at national and local levels, with potential economic, ecological, social, and security benefits. Forty-two African countries are net oil importers. This makes them particularly vulnerable to volatility in global fuel prices and dependent on foreign exchange to cover their domestic energy needs. The goal therefore is to reduce the high dependence on imported petroleum by developing domestic, renewable energy. But can this objective be achieved while leaving a minimal social and environmental footprint? A fundamental question is if biofuels can be produced with consideration of social, economic and environmental factors without setting unrealistic expectation for an evolving renewable energy industry that holds such great promise. The overall performance of different biofuels in reducing non-renewable energy use and greenhouse gas emissions varies when considering the entire lifecycle from production through to use. The net performance depends on the type of feedstock, the production process and the amount of non-renewable energy needed. This paper presents an overview of the development of biofuels in Africa, and highlights country-specific economic, environmental and social issues. It proposes a combination framework of policy incentives as a function of technology maturity, discusses practices, processes and technologies that can improve efficiency, lower energy and water demand, and further reduce the social and environmental footprint of biofuels production thereby contributing to sustainable development.

Contents

1. Introduction

Access to secure, sustainable and affordable energy is a prerequisite for sustainable development in developing countries

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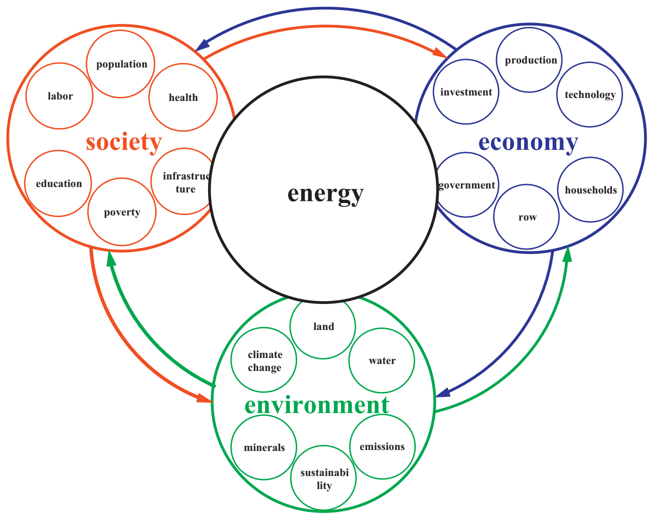

Fig. 1. Interrelationships between access to energy and sustainable development [3].

(Fig. 1). Energy sufficiency and security is a key to development and prosperity since it provides essential inputs for socio-economic development at regional, national and sub-national levels; thereby providing vital services that improve the quality of life [1]. The access to affordable energy is an essential component of achieving the Millennium Development Goals, including reduction in hunger and poverty, facilitating education and communication, enhancing health care services and responding to climate change. The inability of many African countries to provide good and adequate energy services has been a major constraint to their development and biofuel can play a vital role in this regard. Renewable energy technologies (RETs) in general and biofuel specifically, offer developing countries some prospect of self-reliant energy supplies at national and local levels, with potential economic, ecological, social, and security benefits [2].

The energy resources in Africa are unevenly distributed [4]. For example, Africa has 9.5% of the world's proven oil reserves and contributes 12% to global oil production. However, this resource is concentrated in only four countries—Nigeria, Algeria, Egypt and Libya. A few countries in Africa are energy exporters; while the majority (forty two African countries) are net energy importers. They import petroleum products at a cost that places a heavy economic burden and reduces energy security and sovereignty. This implies a pivotal role for regional cooperation and improving regional trade in energy. There is thus an urgent need for substantial investment in domestic energy infrastructure for social improvement and economic growth [4]. In addition, there is an urgent need to facilitate trade in energy by strengthening regional and intercontinental infrastructure such as electricity transmission lines, oil and gas pipelines to improve distribution of energy both within Africa and other continent (e.g., within Europe). Expanding national and regional infrastructure would also increase the efficiency of how Africa uses its energy resources, thus enabling Africa to increase its reliability of supply and reduce its dependence on oil imports. This would improve energy security and increase access to energy services.

Biofuels development, particularly in the context of African development, is a controversial issue that has recently attracted considerable interest among policymakers, development practitioners, donors and other stakeholders. According to the Sustainable Development Commission [5], biofuels can lead to a substantial reduction in greenhouse gases emissions. These reductions require careful measures in crop selection management, subsequent processing and transport of biofuels to the point of use.

Table 1
Biofuels potential in selected African countries in megalitres (ML) [7].

Country	Raw material	Biodiesel (ML)	Bioethanol (ML)
Benin	Cassava		20
Burkina Faso	Sugarcane		20
Ivory Coast	Molasses		20
Ghana	Jatropha	50	
Guinea Bissau	Cashew		10
Mali	Molasses		20
Malawi	Molasses		146
Kenya	Molasses		413
Ethiopia	Molasses		80
Niger	Jatropha	10	
Nigeria	Sugarcane		70
Sudan	Molasses		408
Swaziland	Molasses		480
Senegal	Molasses		15
Tanzania	Molasses		254
Togo	Jatropha	10	
Uganda	Molasses		119

However, the reduction in greenhouse gas emissions during biofuel production has to be balanced against any environmental and social detriment; such as changes in land-usage and practices and deforestation.

There currently exists at least five different forms of biofuels [6]: (a) bioethanol, made from starch rich crops such as sugarcane, wheat, cassava, sorghum and maize, (b) biodiesel, made from oil rich seeds including soya, oil palm, jatropha, (c) biogas produced from the biological breakdown of organic matter (animal or human wastes and other biomass), (d) biomethanol made from cellulosics and (e) biohydrogen made from biomass or by converting methane through steam reforming. It is pertinent to note that only (a)–(c) are operational in the continent, and the biofuels used today in Africa are bioethanol and biodiesel. These energy carriers can be used to fuel car engines, either alone or by blending with petroleum fuels. Bioethanol and biodiesel are the most established biofuels because: (i) they are produced using established methods, (ii) they can easily be distributed in existing transport and distribution infrastructure, (iii) they are considered as renewable energy forms that can substitute non-renewable energy sources, thereby contributing to sustainable development, (iii) they require considerable land area for their production and utilise the established agricultural practices and infrastructure, (iv) the energy, given certain preconditions, is considered as commercially competitive on a global scale.

A review of all the biofuel products currently available on the market revealed that ethanol is the most promising product that can be produced from different raw materials by African countries. It can be noted from Table 1 [7] that many countries produce ethanol from molasses; only Burkina Faso uses sugarcane. Jatropha and oilseed are the main feedstocks for producing biodiesel which is used to run stationary generators for electricity generation and as a diesel substitute for transportation. Although many countries grow Jatropha, only Togo, Mozambique, Ghana and Niger have large Jatropha farms. It is worth noting that South Africa has placed Jatropha on the list of invasive species. Many African countries are located within the tropics with considerable arable lands, fertile soils and a favourable climate for growing many crops including energy crops [7].

This paper analyses the state of biofuels in Africa and highlights the country specific environmental and social-economic issues. It proposes a combination framework of policy incentives as a function of technology maturity based on international practice. In addition, practices, processes and technologies that can dramatically improve efficiency, lower energy and water demand, and further reduce the environmental footprint of biofuels production are discussed. This paper will be of benefit to the energy policy-

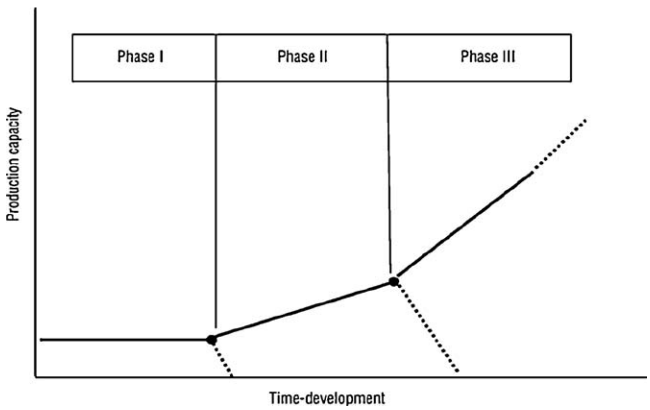

Fig. 2. The three-stage model of biofuels development
Adapted from [8,9].

makers, development practitioners and planners, not only on the African continent but also in other developing countries, to help ensure that the production of biofuels is sustainable and to accelerate the transition to a green economy.

2. State of biofuel development in Africa

Biofuels, otherwise known as agro-fuels when grown under commercial agriculture farming methods, have divided development practitioners and policy makers on a number of issues with intense debates on the benefits and detriment of its development. The demand for biofuels is rapidly increasing throughout the world particularly in industrialised countries such as Germany, Canada, Spain, USA and New Zealand [4]. There are also significant public and legislative attention given in developing countries like Brazil and India [4]. In the African continent, relatively little effort has gone into promoting biofuels, despite the estimated large resource base and biofuel potential. There is a general lack of coherent biofuel development strategy in Africa despite the increase in the price of petroleum-based fuels, uncertainties regarding future oil reserves as well as the climate change concerns.

There are very few operational commercial biofuel systems in Africa. The biofuels development can be described in phases represented in Fig. 2 (adapted from [8,9]).

Phase I consists of the very first ideas and thoughts of biofuel development until the actual adoption of the ideas on the part of decision-makers who are then motivated to put these ideas into practice. The end of Phase I is the political decision to invest money and other resources into biofuel research. Phase II is characterised by research efforts, pilot projects, establishing a framework (policy/strategy formulation) and financially supported technical trials. Phase III is marked by the implementation of a biofuels economy based primarily on commercially feasible production, distribution and the market use of biofuels. Most African countries are still at the first phase of biofuel development [9].

In response to the increase in the promotion of biofuels, several African countries are making efforts to introduce biofuels specific policies. A few countries in the African continent started a number of biofuels initiatives since early 1980s [7]. Fuel ethanol has been produced in Zimbabwe since 1980 with first molasses based ethanol plant. This was stimulated by the economic sanctions and foreign-exchange limitations imposed during colonial rule as a means of generating an independent, self-sufficient source of automotive fuel. Since 1980, Zimbabwe pioneered the production of fuel ethanol for blending with gasoline in Africa (most gasoline sold in Zimbabwe since 1980 contained 12–15% ethanol) and production capacity has exceeded 37.5 million litres since 1983, though actual production stood at only 22.7 million litres in 2004. The ethanol plant was designed to operate on a variety of feedstocks using different grades of molasses, cane juice, or even raw sugar itself [4].

Malawi has very favourable economic conditions for ethanol due to government policy to reduce the volume of imported fossil fuels. Malawi had been continuously producing ethanol and blending (10%) it with gasoline since 1982, although the production volume has fluctuated significantly over the years [10]. The implementation was in response to the Iranian oil crisis in the early 1980s. Ethanol is produced from sugar molasses predominantly at Dwangwa Estate Plant on the lakeshore and Malawi's ethanol company Ltd. produces about 10–12 ML per year. The total ethanol production in Malawi is currently about 30 ML which is used to complement the imported fuel (estimated at between 80 and 90 million litres per year) and used mainly in a 15% blend with gasoline [7,11,12]. To date Malawi has sustained the 10% alcohol blend in petrol. The Malawi biofuels programme has also been sustainably integrated into the country's mainstream agriculture and economy.

In 2004, Mauritius started producing and shipping bioethanol to the E.U. with plans to export up to 30 ML per year [13] Existing information on ethanol plants in Nigeria are scanty after the collapse of the only government commercial ethanol plant, Nigerian Yeast and Alcohol Manufacturing Company (NYAMCO), which was established in 1973. However, there are strong indications that Nigerian cars may start running with a combination of petrol and 10% ethanol. This may stimulate renewed bioethanol production. Other commercial ethanol plants also exist in countries such as Mozambique, Tanzania, Zambia, Kenya, Angola, Swaziland, Egypt, Ethiopia and Uganda. In Uganda, the government is responsible for facilitating the development of biofuels sector through policies and regulations, the provision of incentives, extension advice, information and market infrastructure. Several countries have facilities that are in very poor condition due to years of unrest and/or lack of investment.

Currently, there are no operational large scale (commercial) biodiesel plants in the continent. The biodiesel market is mainly characterised by several small- and medium-scale producers. Most of the countries in Africa except South Africa, Mozambique and Zimbabwe are still in the first stage of biodiesel development. South Africa's biodiesel market is mainly characterised by several small- and medium-scale producers while Zimbabwe recently inaugurated Africa's first ever commercial biodiesel plant. The 6 million US dollar biodiesel plant which processes Jatropha, cotton seed, sunflower and soya, among other feedstock, has the capacity to produce 100 ML annually [14]. The plant is expected to save up to US$ 80 million a year in foreign currency from the importation of diesel. However, the plant is operating at less than 5% capacity which is attributed to an acute shortage of feedstock [15]. The first biodiesel plant in Mozambique was erected in Matola, in 2007 by Ecomoz as a result of the mandate from the Mozambique government. To address the erratic supply of raw materials (mainly Jatropha curcas and coconut copra), the project devised a way of securing large quantities of feedstock via an integrated community involvement programme. This programme focuses on utilising available community resources by stimulating economic and social activities in previously forsaken rural communities through the establishment of rural Trading Points [16]. The use of vegetable oil as a source of fuel for energy production has been explored in some African countries such as Mali and Uganda. For instance, in Mali, the Mali-Folke Center, a local NGO supports Jatropha for biodiesel and power generation.

The production and commercialisation of biodiesel in Africa could provide an opportunity to diversify energy and agricultural activity, reduce dependence on fossil fuels (mainly oil) and contribute to economic growth in a sustainable manner [9].

3. Factors responsible for increased biofuels production in Africa

The growing interest in biofuels in many African countries can be explained by factors such as high crude oil prices, fluctuations in prices due to geopolitical uncertainties, local and global environmental impacts of fossil fuels such as climate change, opportunities for job creation, new research and technological advances, economic development, and the need to increase the access to energy services so that development meets the Millennium Development Goals and is on sustainable path [17,18]. The under-utilisation of land with agricultural potential in many African countries has also contributed to increased push by domestic and international interests towards exploiting this productive capacity. Most developed countries (especially, European Union) are also moving from voluntary legislation to obligatory legislation; imposing market share of biofuels in the transport sector and applying a mandatory blending legislation [19]. To meet the target of 5.75% market share of biofuel in 2010 and about 8% by 2020, EU countries would need to import feedstock (and/or biofuel) from elsewhere, due to lack of sufficient arable land for energy crops and the well-established regulations safeguarding forests and governing land use [19,20]. Africa is seen as the single largest potential for the production of the bioenergy crops globally. The rapid development in the biofuels sector and the foreign interest and investment in African biofuels has created problems for governments to coordinate and guide such production. A number of African countries have signed agreements with foreign investors to devote large parcels of land for biofuels production [18].

Many of these biofuel developments have been carried out without the existence of policies and regulatory framework. These could result in negative impacts on the environment such as deforestation, biodiversity loss, land use and other social problems and social problems such as reduced land for food production. Only a few African countries have established a clear policy framework to ensure the development of sustainable biofuel industry. This will be discussed further in other sections of the paper.

African countries are at the various stages of initiating commercial production of biofuels to capture the benefits of this new market value chain. This predominantly led to large-scale mechanised feedstock/biofuel production based on a model of industrial agriculture that uses costly external inputs (petroleum-based fertilisers, pesticides and fuels) and measures success and effectiveness largely by the economic benefits with little consideration of social and environmental costs and benefits. It is vital that biofuel development in Africa is sustainable. Sustainable biofuel development will not only stimulate investment in Africa's neglected agricultural sector, but also offer additional benefits in terms of poverty reduction, food crop production and energy diversification. However, governance and policy is required to ensure that these developments are carried out in a way that helps African countries achieve sustainable development. The concept of biofuels sustainability is extremely complex and the views are diverse [21]. However, there is an evident commitment to sustainable biofuels development in Africa at the highest political levels. For instance, the Addis Ababa Declaration on Sustainable Biofuels Development in Africa held in August 2007, the participants at the First High-level Biofuels Seminar in Africa, highlighted challenges that decision makers face in determining strategies and policies for the sustainable development of biofuels [18]. Despite the inherent belief that biofuels are sustainable, this is not necessarily true. To assess the sustainability of biofuels, the impact of the production, trade and final conversion of the biofuel must be analysed using an integrated approach and taking into account the three interlinked criteria of sustainable development such as the social impacts (social well being), environmental impacts (maintaining or improving environmental quality) and economic impacts (economic viability of biofuels production and associated welfare considerations) [22].

4. Sustainability issues relevant to Africa

Sustainability issues related to the development of biofuels have been discussed and debated in different fora. The main issues are as follows:

4.1. Food versus fuel

The large-scale, mechanised production of energy crops is not appropriate for many developing countries due to food security concerns [23]. This is in particular when high quality soils are predominantly occupied with energy crop production and not available for food production. The line between energy and agriculture in some African countries is becoming blurred. In West Africa for instance, Ghana is significantly attracting foreign investment in energy crops [24]. For example, the last four years has seen Norwegian, Brazilian, Dutch, Swedish, German and British firms all competing for farmland to grow energy crops in different parts of the country. Seven private companies from these countries are currently farming about 136,000 acres of land for biofuels and more investments are expected in the next few years [24]. China on the other hand acquired seven million acres (28,328 km^2) in the Democratic Republic of Congo to grow the world's largest palm oil plantation for motor fuel. Trans4mation Agric-tech secured 25,000 acres in Nigeria for bioenergy cultivation [24]. In the East African region, Britan's CAMS Group recently bought 112,000 acres for jatropha in Tanzania while Sun Biofuels, also of the UK, bought 13,500 acres in Tanzania for the same purpose. Germany's Flora EcoPower has lined up 32,000 acres in Ethiopia. In Kenya, Energy Africa Ltd. started introducing Jatropha to the poor farmers fields [24]. In contrast, Sweden's Skebab purchased 247,000 acres in Mozambique and China is negotiating for five million acres in Zambia to grow Jatropha.

In the Southern Africa, the rapidly declining crop production left millions facing starvation, with rural populations being the most affected [25]. Although governments favour the establishment of a strong biofuels industry, they lack the financial resources to incorporate feedstock production into an already strained agricultural sector. In addition, most countries in Southern Africa are net importers of staple crops. Opportunities for growing crops for biofuels may therefore be determined by the ability of the countries in the region to first increase production to sustainable levels for food requirements [25].

Some studies have shown that increased demand for biofuels is responsible for about 30% of the weighed grain price increase from 2000 to 2007 [26]. Looking at the longer-term impacts of expanded biofuel production, OECD [27] estimates a 20% increase of the price of vegetable oil in the year 2014 as a result of the combined effects of the U.S., E.U., and Canadian biofuel blending mandates. The rise in food prices resulting from biofuel production has a huge impact on a country's food supply and food security. Many Africans spend over 50% of their share of income on food [28] and many African countries import food to meet their domestic energy demands. In the year 2000, the average total imported cereal demand in sub-Saharan Africa was 33%, with Sudan, Gambia and Zambia reaching a high dependency level of more than 80% FAO [29].

Biofuels development is argued to have positive benefits in ensuring household food security through increased incomes and the growing export markets for energy crops. There are however a number of factors that are not explicitly accounted for in many of the partial-equilibrium frameworks that generate these conclusions. Analysis of net trade results [26] indicates that production

levels increase in order to fuel export growth, which consequently earns foreign exchange and creates employment opportunities within the agricultural sector. Therefore, the predicted increase in food prices under biofuel expansion scenarios may be offset by the added benefit of income gains directly through job creation related to biofuel production, and in general from higher feedstock prices that farmers can earn. In some countries in Africa, concerns surrounding food security have resulted in governments actively cautioning the development of biofuels. In Tanzania for instance, as a result of mounting pressure from farmers and environmental groups, the government suspended all biofuel investments and halted land for biofuel development [30]. In South Africa, maize was excluded from ethanol production amid food security concerns in the draft biofuel strategy.

Biofuel developments also present a potential competition between biomass systems for biofuels production and the use of biomass resources for animal feed, bedding, fertiliser and construction materials [31]. Of particular concern are threats from business orientated production of biofuels that may require opening of forests or acquisition of land from rural dwellers for growing energy crops. Additionally, the market prices of energy crops may be greater than for food and induce the diversion of resources away from food to biofuel production; thereby threatening food security [32].

4.2. Land use and tenure security

Land is central to the issue of biofuel production. In order to gain maximum benefit from biofuels, large tracks of land are required for biofuel crop production. Frequently, the land is taken away from communities who are socially and economically vulnerable, and whose land tenure is not formal and/or insecure thereby negatively impacting the poorest Africans. In Tanzania most of the land that is suitable for biofuel production belong to around 11,000 villages where smallholder production is the mainstay of rural livelihood [33]. Other African countries with community and customary oriented forms of land governance include Ethiopia and Mozambique. In Ethiopia, arable land and wooded areas are being cleared without taking into consideration the loss to biodiversity. Environmental impact assessments are not required or are performed in an ad hoc manner [34].

Biofuel systems can be developed in diverse land-use situations as shown in Fig. 3 [35].

Conventional management methods are efficient in differentiating these land uses according to physical criteria. However, actual land uses, not only change according to physical factors, but also because of change in demands from market opportunities, society and stakeholders' entitlements.

Studies have also shown that the production of biofuel crops can have significant impact on water demand (e.g., [36]). Water is required during production for mixing, washing and evaporative cooling. The biggest water requirement, however, arises from irrigation. While plants like Jatropha can do well in semi-arid areas, it may require some irrigation. The fundamental question for Africa is whether it is wise to use irrigated land to produce biofuel crops (e.g., sugarcane), when the same land has also great potential for food production.

4.3. Climate change and environment

Biofuel development has been stimulated by the opportunity to reduce greenhouse gas emissions. However, there is some recent evidence indicating that biofuels may emit more greenhouse gases than it saves [37]. For example, the destruction of natural ecosystems not only releases greenhouse gases into the atmosphere when they are burned and plowed, but also deprives the planet of natural sponges to absorb carbon emissions. However, the biofuels net GHG depends on case by case analysis. Most African countries have made commitments to reduce greenhouse gases through their signatories to the United Nations Framework Convention on Climate Change (UNFCCC). The question therefore is whether biofuels will be effective to achieve this goal.

4.4. Impact on poverty alleviation

The development of biofuels occurs in the rural areas where there are opportunities for agriculture. These areas contain the poorest Africans where many small-scale and subsistence farmers reside. Biofuels is argued to therefore contribute to poverty alleviation through provision of energy by increasing the income per capita [17]. There are issues as to how this wealth will be distributed and the equity and improvement in the quality of life of communities affected by biofuel developments. Countries such as South Africa and Mozambique are committed to promote biofuels mainly in response to national poverty alleviation agenda. Whether biofuel development enables the achievement of this goal is an issue that needs comprehensive investigation.

4.5. Gender issues

Women in developing countries are responsible for securing energy and water for their households and doing the majority of work in the field. There is therefore the potential that biofuels could assist in liberating women from these toilsome burdens [38]; thereby empowering women by making fuels more accessible and affordable while freeing more time for other activities.

The production of liquid biofuels is rapidly increasing in developing countries, mainly due to the establishment of large-scale biofuel feedstock plantations. This results in potential socio-economic benefits, particularly in terms of agricultural employment, as well as risks, which tend to be context-specific. The environmental and socio-economic transformations prompted by the growing global demand for liquid biofuels might have different impacts on men and women in developing countries. Men and women within the same household as well as male- and female-headed households, could face different risks, particularly with regard to their access to and control of land and other productive assets, their level of participation in decision-making and socioeconomic activities, employment opportunities and conditions, and their food security.

Large-scale plantations for the production of liquid biofuels require an intensive use of resources and inputs to which smallholder farmers (particularly female farmers) traditionally have limited access. These resources include land and water, plus chemical fertilisers and pesticides. In most developing countries, there are significant gender gaps particularly in land ownership. For instance, in Cameroon, while women undertake more than 75% of agricultural work they own less than 10% of the land. Similar disparities have been identified in Tanzania, Kenya, Nigeria and other countries in Sub-Saharan Africa [39]. In addition, women, generally lack access to formal credit schemes and are generally unable to use land as a collateral thereby limiting their development prospects [40]. In Nigeria, only 3% of women receive credit from banks, against 15% of men; moreover, although the average value of the loan obtained by women is only 42% of that of men, the percentage of collateral required is regularly higher for women [41]. Therefore, female-headed households, compared to male-headed households, might face more barriers to accessing the market for these external inputs and thus participating in biofuels production. The economic development and income-generating opportunities created by the increasing demand for biofuels might in the beginning benefit men (and male-headed households) more

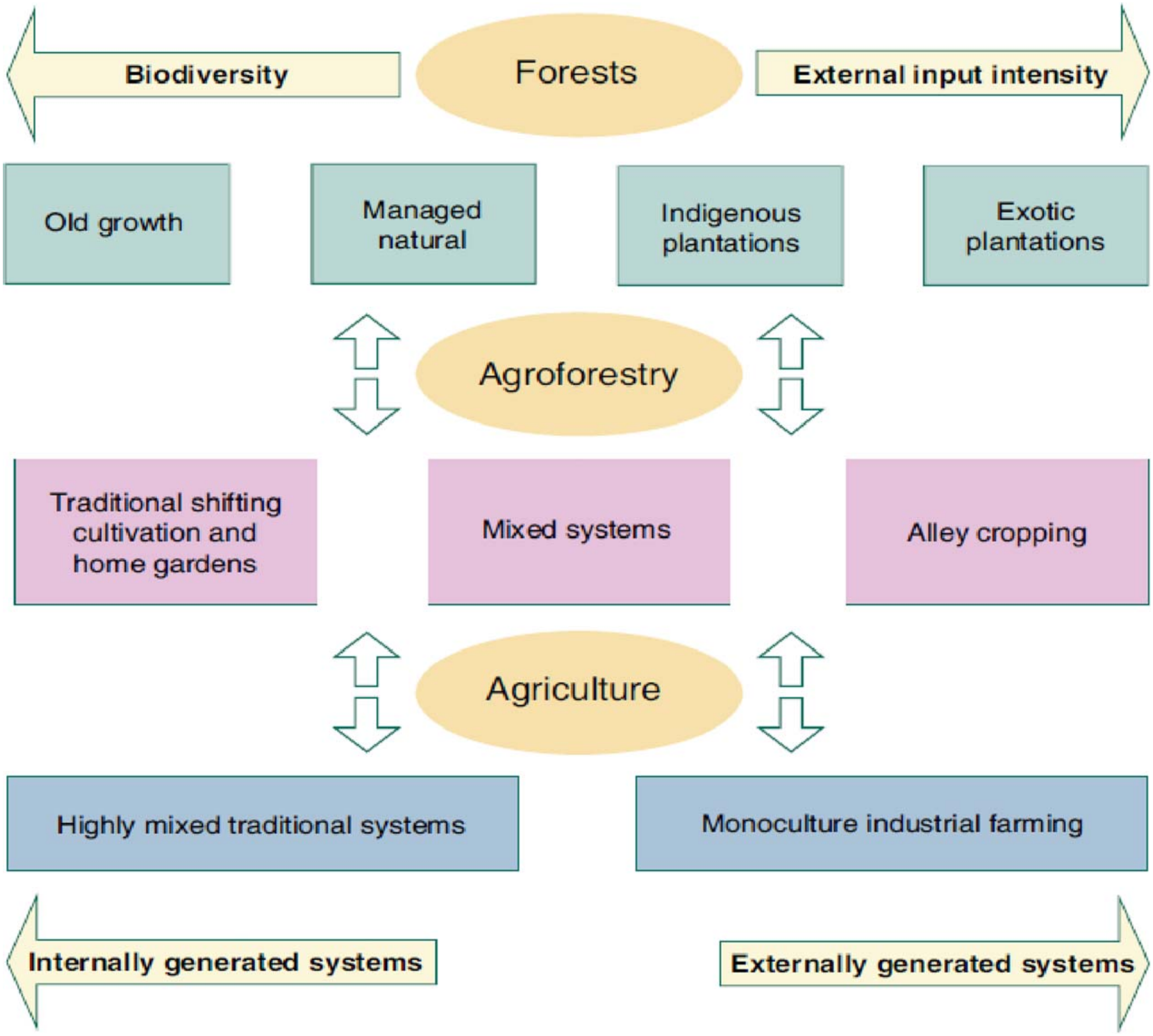

Fig. 3. Land use spectrum as a basis for biofuel development [35].

than women (and female-headed households), due to underlying differential access to resources which would need to be addressed over time. [42].

Marginal lands are particularly important to women. There is evidence, for instance, that in several Sub-Saharan African countries, women are often allocated low quality lands by their husbands. It has been documented, for example, that in Côte d'Ivoire and in the northern part of Ghana, women tend to be allocated land that has already been under cultivation for several consecutive years and is therefore low in fertility [43]. Another study has also found that, in Burkina Faso, women tend to be pushed to marginal plots as a consequence of environmental problems affecting the quality of agricultural land [41]. On marginal lands, women have traditionally grown crops for household consumption, rituals and medicinal uses. The conversion of these lands to plantations for biofuels production might therefore cause the partial or total displacement of women's agricultural activities towards increasingly marginal lands, with negative repercussions for women's ability to meet household needs, including traditional food provision and food security. Furthermore, if land traditionally used by women for food crop production switches to energy crop production, the roles men and women play in decision-making concerning household agricultural activities may be altered. In particular, women's ability to participate in land-use decision-making may be reduced and the amount of land they control will decline [42,44].

4.6. Biofuel policies/strategies

The assessment of energy policies has an important implication in shaping the trend of biofuel development in Africa, but has received little research to date. Most energy policies in sub-Saharan Africa were developed during the last 5 years and many countries are still in the process of developing their energy policies [7]. However, the energy policies have general policy statements on biofuels development without concrete strategies and an appropriate institutional framework for implementation. In some cases, biofuels have been implemented without any policy in place. In the case of Mozambique, the national energy policy is not yet finalised, but the country has already adopted preliminary regulations to foster the large-scale production of biofuels. The policy proposes the gradual introduction of blending of petrol (gasoline) with ethanol; and biodiesel with fossil diesel, initially, at 5–10% [7]. There is clearly a need for establishing a regulatory authority which can be responsible for coordinating biofuels research and development activities in order to direct, facilitate and monitor sustainable biofuel development.

Table 2
List of countries, regional bodies and policies in some selected African countries.

Country	Regional representation	Regional body	Key feedstock's	Presence of policies
Ghana	West Africa	ECOWAS	Jatropha, palm oil, sugarcane	Energy policy, renewable energy
Angola	Southern Africa	SADC	African oil palm	Biofuel law[a]
Mozambique	Southern Africa	SADC	Jatropha, sugarcane	Renewable energy policy, biofuels strategy
Nigeria	West Africa	ECOWAS	Palm oil, sugarcane	Energy policy, biofuels strategy
South Africa	Southern Africa	SADC	Sunflower, canola, soya, sugarcane	Energy policy, renewable energy white paper, and draft biofuel industrial strategy
Tanzania	East Africa	EAC	Jatropha	Energy policy-process of developing a strategy
Zambia	Central/Southern Africa	SADC	Jatropha, sugarcane, sorghum	Energy renewable energy, energy and biofuel industrial strategy
Zimbabwe	Southern Africa	SADC	Jatropha, sugarcane and OIL seeds	Draft energy policy
Uganda	East Africa	EAC	Jatropha, sugarcane	Energy policy
Benin	West Africa	ECOWAS	Palm oil	Could not establish
Mali	West Africa	ECOWAS	Jatropha	Renewable energy, energy and biofuel industrial strategy
Malawi	Southern Africa	SADC	Sugarcane	Malawi's national energy policy
Senegal	West Africa	ECOWAS		Energy policy
Mauritius	East Africa	SADC	Mostly sugarcane	Multi Annual Adaptation Strategy (2008, 2013), which includes an Ethanol Development Strategy 2008
Swaziland	Southern Africa	SADC	Sugarcane	National energy policy – Renewable Energy Action Plan

[a] Angola's parliament on the 25th of March 2010 approved a new law to regulate the production of biofuels, opening the way for multi-billion dollar investments in the sector.

5. Policies for sustainable biofuel development

Biofuels are being developed in a very complex, dynamic and diverse context. Therefore, in assessing performance of biofuel policies, there is need for a framework for sustainable development with the use of sustainable criteria based on the potential social, economic and environmental impacts. However, many of the policies are being recommended and developed by global commercial interest rather than national or regional government. This has resulted in many differing and contrasting frameworks and policies. To date, only a few African countries have implemented effective support policies for renewable (biofuels) energy (Table 2) (adapted from [45]). Most of the policies have been declaratory rather than been specific and proactive and, in most cases, the policies are yet to be ratified by the parliaments (signed into law). However, delays in regulatory formulation and implementation of policies/strategies will hinder the market development of biofuel industry.

The policies in different countries have engaged different role players and stakeholders. In Nigeria and Uganda the government facilitates development, provides stimulus for private sector investment, and monitors and co-ordinates the energy sector activities. Thus, the government and public universities are still the key role players in the energy sector. This contrasts with South Africa, Tanzania, Zambia and Malawi where the private sector, foreign companies and non-governmental organizations are responsible for biofuels strategy and policy recommendation and formulation. Additionally, with the exception of South Africa, most polices were formulated without analysis of the impact of biofuels sector development on employment, food security and the environment [7].

The Roundtable Sustainable Biofuels (RSB) principle aims to define a single biofuel sustainable framework and standards that have undergone considerable global stakeholder consultation [45]. A wide variety of policies and incentive schemes in place can be effectively applied depending on the specific technology and country [46]. However, to date, non-economic barriers such as administrative bottleneck and bureaucracy have significantly hampered the effectiveness of renewable support policies and driven up costs in many countries, irrespective of the type of incentive scheme [46]. It is therefore recommended to move beyond discussions over which specific incentive scheme functions best.

The assessment must include the entire policy framework into which incentive schemes are inserted and effectively implemented. Overall, the effectiveness and efficiency of renewable energy policies are determined by the adherence to key policy design principles (outlined below), as well as the consistency of measures, administration and regulation. Renewable policy design should reflect five fundamental principles outlined in the IEA/OECD [46] report, namely the:

- removal of non-economic barriers, such as administrative hurdles, obstacles to grid access, poor electricity market design, lack of information and training, and the tackling of social acceptance issues – with a view to overcoming them – in order to improve market and policy functioning
- need for a predictable and transparent support framework to attract investments
- introduction of transitional incentives that decrease over time in order to foster and monitor technological innovation and move technologies quickly towards market competitiveness
- development and implementation of appropriate incentives guaranteeing a specific level of support to different technologies based on their degree of technology maturity (Fig. 4)
- consideration of the impact of large-scale penetration of renewable energy technologies on the overall energy system, especially in liberalised energy markets, with regard to overall cost efficiency and system reliability.

Reflecting these five principles in an integrated approach allows two concurrent goals to be achieved, namely the exploitation of the "*low-hanging fruit*" of abundant renewable energy technologies (RETs) which are closest to market competitiveness while preserving and implementing the long-term strategic vision of providing cost-effective options for a low-carbon, sustainable energy future.

There are two different types of support mechanism (direct and in direct support mechanisms) available to stimulate RET in general and specifically biofuels development. Direct policy measures aim to stimulate the installation of RETs immediately, whereas indirect instruments focus on improving long-term framework conditions. Besides regulatory instruments, voluntary approaches for the promotion of RETs also exist, mainly based on consumers' willingness to pay premium rates for green biofuel. Further important classification criteria are whether policy instruments address price or quantity, and whether they support investments or generation.

Analysis suggests that policy frameworks which combine different technology-specific support schemes as a function of RET maturity would be best suited to successfully implement the key policy design principles and foster the transition of biofu-

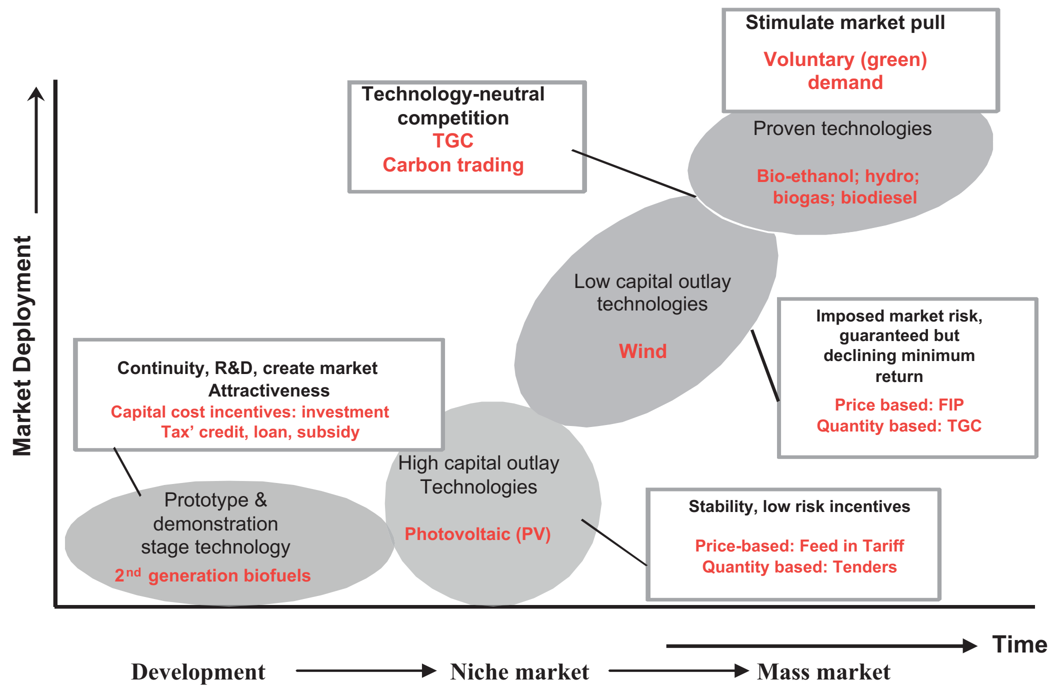

Fig. 4. Combination framework of policy incentives as a function of technology maturity [46].

els towards market integration. Governments should develop a combination policy framework that applies market principles as technology maturity and deployment increase. This is possible with a range of policy instruments, including price-based, quantity-based, research and development (R&D) support, and regulatory mechanisms [46]. This is illustrated in Fig. 4. As a general principle, less mature technologies further from economic competitiveness need, beyond continued R&D support, very stable low-risk incentives: – capital cost incentives and feed-in-tariffs (FITs) such as those recently introduced to South Africa, and tenders – a regulatory quantity-driven support mechanism (strategies). Depending on the specific market and resource conditions, and level of market integration across countries, technology banding may be necessary in a transitional phase or may be bypassed in favour of a technology-neutral tradable green certificate (TGC) system [46]. Once the technology is competitive with other energy services and is assessed for sustainability (economic, social and ecological), they are ready to be deployed on a large scale, and the RET support systems can then be phased out. Henceforth, renewable energy technologies will compete on a level playing field with other energy technologies.

South Africa and Ghana have developed specific biofuel strategies with specific targets. The South African Industrial biofuel strategy aims to achieve a penetration level of 2% of biofuels (400 million litres per annum) in the national energy supply by 2013 [47]. The crops targeted for the production of biofuels include canola, soybeans and sunflower for biodiesel and, sugar beet and sugarcane for bioethanol [47]. The Government of Ghana has set a target of substituting 20% of the national gas and oil consumption with biodiesel by 2015, and 30% of the national kerosene consumption with Jatropha oil by 2015. The policy also aims at improving the efficiency of biodiesel production in order to reduce production costs. In the case of Mozambique, the national energy policy is not yet finalised but the country has already adopted preliminary regulations to foster the large-scale production of biofuels. The policy proposes the gradual introduction of blending of petrol (gasoline) with ethanol and biodiesel with fossil diesel, initially, at 5–10% [7].

6. Practices and technologies that can improve the sustainability issues

The environmental concerns about biofuel feedstock production are the same as for agricultural production in general, and existing techniques to assess the environmental impact offer a good starting point for analysing the biofuel systems. The adoption of “good practices” in soil, water and crop protection, energy and water management, nutrient and agrochemical management, biodiversity and landscape conservation, harvesting, processing and distribution could ensure biofuel sustainability in Africa.

One of the greatest costs in an ethanol plant is the energy it takes to generate the heat needed for the fermentation and distillation of the bioethanol product. As a result, ethanol producers are continually motivated to reduce energy costs and improve efficiency, productivity and environmental stewardship [48]. The Brazilian model of ethanol production—a distillery annexed to a plantation primarily engaged in production of sugar for export could help reduce emission by 70–90%. The main objective of this model would be to produce sugar rather than alcohol, sharing several common processes and resources such as boilers, effluent treatment and personnel. This model of ethanol production may offer solution to African countries without compromising food production. The energy balance of bioethanol from crops is thought to be marginally net positive with current farming practices (e.g., energy balance of 1.3 for corn in the USA and up to 8 for sugarcane in Brazil, [49]). For the traditional corn (maize) fermentation, up to 67% of the energy inputs are for the fermentation and distillation process, while the remaining 23% are energy costs associated with the biomass production (agricultural crop) [50,51]. The slow reaction rates result in large fermented volumes that contribute to capital cost, water usage and to the subsequent volume of wastewater generated, all of which influence production cost. It is estimated that 3–10 litres of wastewater are generated per litre of ethanol produced. The high water content (typical ethanol concentrations achieved are 10–16% (v/v)) results in the need for a subsequent energy intensive distillation process. There are also several developments that have

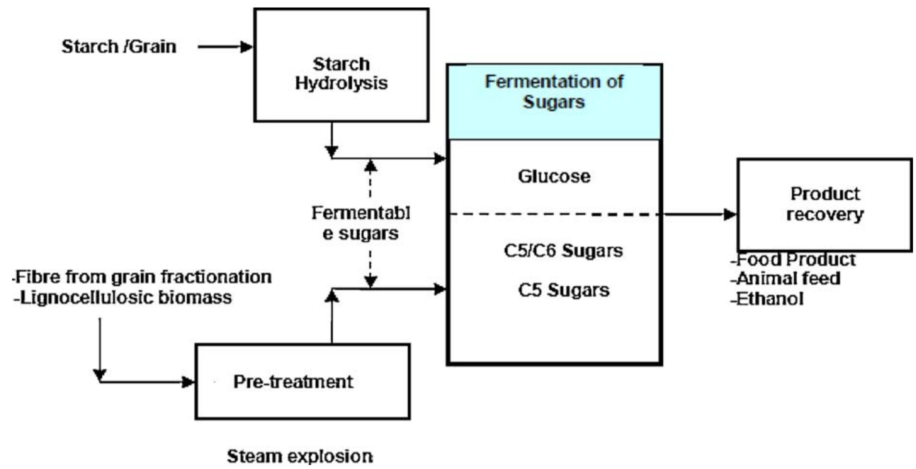

Fig. 5. Integrated cellulosic and dry mill ethanol process.

optimised bioethanol fermentations for improved yields and more efficient ethanol distillation processes [52,53]. In particular, membrane distillation (molecular sieve technology) has been shown to be the most efficient and cost effective option among the available distillation processes [54,55] and it can significantly reduce the energy inputs involved in traditional ethanol distillation. An interesting alternative fermentation technology has developed a unique process in which a range of waste materials undergo thermal gasification at high temperature into CO, CO_2 and H_2 [56]. The CO is then transformed into ethanol by the acetogenic bacterium *Clostridium ljungdahlii* and the ethanol distilled. Typical yields are 340 litres per tonne bio-solids (municipal solid waste, biomass waste, animal wastes, etc.), increasing to 680 litres per tonne as the oxidation state of the bio-solids decreases (used tyres, hydrocarbons). There is an opportunity for a balanced approach to the dilemma of using crops for fuels with the use of second grade or excess food and other agricultural wastes for the production of biofuels. If this approach is effectively regulated, there can be a fundamental premise to protect food prices while still enabling biofuel development. Technologies already exist that can harness the energy from agricultural wastes for the production of biofuels; such as the established technology of biogas production from animal manures and other agricultural wastes and the recent advances in accessing the cellulosic plant waste material for bioethanol. A large proportion of the carbohydrates in plants consist of lignocellulose[1] and the required pre-treatment[2] is a major challenge to the development of cost effective fermentation processes for the conversion of cellulose to ethanol [57]. This situation is changing rapidly and the second generation biofuels are under active development with several new commercial-scale plants that have been commissioned since 2007.[3] A hybrid ethanol production process where a cellulosic-ethanol plant is added to a traditional/conventional dry mill ethanol plant, by integrating the cellulosic front end process to a traditional starch-based ethanol plant show the most promise for commercialisation of cellulosic ethanol production in Africa. This is because it is the least capital intensive approach. The objective of an integrated cellulosic plant is not to have a technology that is more competitive with starch production, but that will compliment the starch technology to expand ethanol production from limited feedstock. The cellulosic ethanol plant is co-located with the starch plant, sharing utilities and support systems. Such a "clip-on" cellulose plant could synergise with an existing site (see Fig. 5).

A fundamental issue with the production of biofuels is the use of land-resources and the competition with food production. Therefore, the biofuel agricultural planning and practices need to be integrated and effectively managed. Historically, the developments in agriculture have concentrated on increasing productivity and effectively exploiting natural resources, but have ignored the complex interactions between agricultural activities, local ecosystems, and society. There is now overwhelming evidence of the negative impacts of modern agriculture on the environment [58,59] and the subsequent cost in the provisioning of ecosystem services that many scientists consider modern agriculture to be an ecological crisis [60].

The global United Nation's Millennium Ecosystem Assessment, shows that 60% of the ecosystem services (such as air and water purification, pollination of crops, natural pest control, food, fibre, fish and wood, and the ability of the ecosystem to mitigate the effects of natural disasters) have been degraded (between 2000 and 2005). Due to the decline in the quality of the natural resource base associated with modern agriculture, the concept of sustainable agriculture has emerged to help ensure the fair, equitable and sustainable use of resources such as biodiversity, water, soil, and fossil fuels [61,62]. Agroecology is an approach that improves food productivity, resilience and security using practices such as intercropping and polyculture to diversify products and increase on-farm biodiversity, mulching and minimum (conservative) tillage to conserve soil moisture and health, and the recycling of wastes for use fuel and fertiliser [63,64].

Conventional farming practices, especially the burning of crop residues and vegetation, intensive hoeing or ploughing, and lack-

[1] Lignocellulose refers to the combination of cellulose, hemicellulose and lignin.

[2] Pre-treatment typically requires several stages involving physical methods (milling, chipping, pelleting), chemical methods (acid hydrolysis, steam explosion, ammonia fiber expansion, organosolve, sulfite pretreatment, alkaline wet oxidation and ozone) and enzymatic methods (cellulase, xylanase and hemicellulase) to liberate the monosaccharide sugars for fermentation.

[3] REN21 (2009). Renewables Global Status Report: 2009 Update p. 16. The cellulosic ethanol industry accelerated development of new commercial-scale plants in 2008. In the United States, plants totalling 12 million litres per year were operational, and additional capacity of 80 million litres per year was under construction (also reported as 26 new plants under development and construction). In Canada, capacity of 6 million litres per year was operational. In Europe, a handful of plants were operational in Germany, Spain, and Sweden, and capacity of 10 million litres per year was under construction. The largest second-generation biofuels plant in the world will come online in Delfzijl, the Netherlands, in 2009, to produce 200 million litres per year of bio-methanol. Globally, additional capacity of at least 1.5 billion litres per year was planned. Industry pioneers include Royal Nedalco (the Netherlands), Econcern (the Netherlands), Iogen (Canada), Diversa/Celunol (USA), Abengoa (Spain), and the Broin & DuPont consortium (USA).

ing restitution of organic matter and plant nutrients, results in soil degradation. Declining soil fertility is linked to water storage and availability and thereby results in declining yields, increased vulnerability of crops to droughts, with food insecurity and increasing poverty. This threatening development calls for a radical change in the way farming is done. What is required are farming systems which imitate tropical ecosystems, i.e. protect soils from rapid degradation, are more productive, and at the same time reduce drudgery especially that of women and children. Conservative tillage (CT) responds to these requirements. This production system provides the means that can prevent further destruction of precious soils, ensuing higher and more stable yields while it reduces production costs (especially the energy input for tillage) and increases labour productivity Steiner [65]. Specifically, in most parts of the African continent, the farming systems are unsustainable and are characterised by extremely low yields, exploitation of natural resources ("soil mining") and an increasing labour input. They are also not adapted to a changing natural and socio-economic environment. Only a drastic change of farming systems, a turn towards a more sustainable management of soils and an increased labour productivity can improve the situation. Conservation tillage (CT), which has revolutionised the farming systems in Latin America within the last decade, may offer a solution to Sub-Saharan Africa, too. There are several African initiatives that are developing agro-ecological approaches. This includes the African Conservation Tillage (ACT) Network which is a fast growing pan-African not-for-profit organization whose membership is voluntary and aims at bringing together stakeholders and players who are dedicated to improving agricultural productivity through sustainable utilisation of natural resources of land and water in Africa [66]. This network was initiated in 1998 at a workshop on Conservation Tillage for Sustainable Agriculture convened in Harare by Gesellschaft fur Technische Zusammenarbeit (GTZ), FAO, the Southern and Eastern Africa base FARMESA, the Zimbabwe Farmers Union and the South African Agricultural Research Council. The specific objectives of ACT are as illustrated below:

- To create forums for, and stimulate the sharing of, the exchange of information and experiences among researchers, extension officers and practitioners, and encourage farmers to increasingly apply methods of soil and water conservation that are environmentally sound and economically viable.
- To encourage the formation of networks in order to promote an institutional and policy environment conducive for the dissemination of conservation tillage practises.

A recent three-year study by the International Assessment of Agricultural Science and Technology for Development (IAASTD) established that, although existing agricultural science and technology can tackle some of the underlying causes of declining agricultural productivity, further developments based on an interdisciplinary approach are needed; starting with the monitoring of how natural resources are used [67]. The increased use of agricultural practices that reduce the cost of externalities and petroleum-based products can improve the sustainability of agricultural production while increasing the socio-ecological benefits. For example, energy can be saved in tractor use by improved control of gears (estimated technical savings of 5–30%), maintenance and developments of diesel engines (10–35%), and reduced tillage (35–70% of energy use for tillage). The use of no-tillage has been shown to increase water retention and improve soil heath [68]. The no-tillage cropping system is a combination of ancient and modern agricultural practices and has rapidly gained popularity due to reduced energy inputs, reduced soil leaching and improved water availability. By the year 2000, as much as 65% of the acreage of crops grown in the United States may be grown by the no-tillage practice. Soil erosion, the major source of pollutants in rural streams, is virtually eliminated when no-tillage agriculture is practiced. The no-tillage system reduces the energy input into corn and soybean production by 7% and 18%, respectively, when compared to the conventional tillage system of ploughing followed by disking. In addition, crop yields are as high as or higher than those obtained with traditional tillage practices on large areas of agricultural land [68,69].

The benefits of composting versus fertilising have been intensely debated, but most studies acknowledge that the application of compost can have the same effect (or better) compared to fertilisers [70]. The practice of composting also reduces environmental and health burdens of on-farm waste and offers the opportunity to generate a valuable local product, compost, that increase food yields and also food security by reducing the need for costly external inputs. A study in sustainable agriculture in Tigray, Ethiopia (2001 through 2005) measured the yields from 14 crops in 779 fields that were treated with compost or chemical fertilisers or had no inputs. Both compost and fertiliser drastically improved crop yields compared to no additions, but the composting was shown to be more effective. Yields were 30% or more for the composted fields compared to those treated with fertiliser; and for some grains (barley, wheat millet) the yields for composted fields were nearly 100% more than using fertiliser. The composting and an agro-ecology approach also brought significant benefits to poor farmers and communities, particularly to women. Among the benefits demonstrated are increased yields and productivity of crops, improved hydrology with raised water tables and permanent springs, improved soil fertility, less weeds, pests and diseases, rehabilitation of degraded lands, and increased incomes [71,72].

The African continent lacks a large oilseed infrastructure (despite its agronomical suitability), storing and crushing facilities, as well as operating commercial-scale biodiesel plants [9]. Small to medium, decentralised (localised) biodiesel production with standards satisfactory to engine manufacturers could therefore be a feasible option for encouraging development in Africa as it would keep more resources and revenue within communities. An agricultural based biodiesel model—a biodiesel plant located very close to an agricultural area with an integrated oil mill is recommended for sustainable production because it brings benefits directly to local communities. This model increases the regional creation of value and, at the same time, introduces biodiesel production in a closed-loop recycling management cycle (see Fig. 6). This biodiesel plant model reduces the feedstock transportation cost due to the close proximity of the feedstock, making it more efficient from the energy and cost point of view. This type of model would be most applicable for wealth creation within a community, thereby increasing the

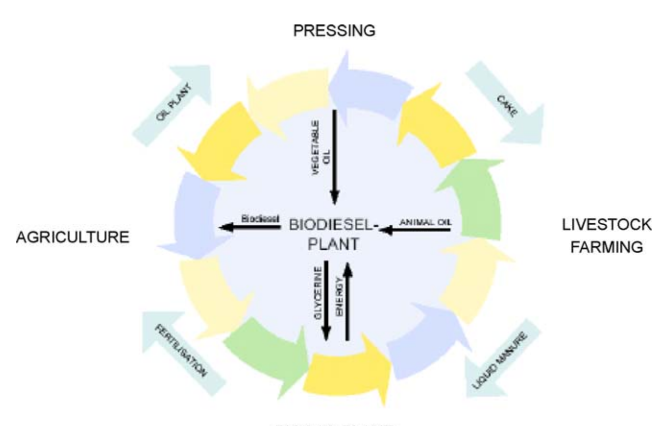

Fig. 6. Closed loop recycling management of agricultural oil-mill based biodiesel plant [9].

standard of living. The oilcake and the glycerine can be used as a source of energy generation such as combustion anaerobic digestion for biogas production for combined heat and power (CHP).

In recent years, the recognition of environmental services and their value has led to efforts to internalize environmental services through direct payments for environmental services (PES). From an economic perspective, the loss of environmental services (ES) is explained by the fact that most of these services present externalities or public goods to which, as long as provided for free, their owners will not give much attention when making land use decisions. The idea of PES consists therefore of external ES beneficiaries making direct, contractual and conditional payments to local landholders and users in return for adopting practices that secure ecosystem conservation and restoration and thus the provision of ES [73]. In this way land users are expected to receive a direct incentive to include ES in their land use decisions, ideally resulting in more socially optimal land uses than would occur in the absence of such payments [73].

Payment schemes for Environmental Services (PES) are flexible mechanisms, which can be adapted to different conditions. They consist of a payment or direct compensation by the users of the service for the maintenance or provision of an environmental service to the providers of the same. This scheme could stimulate sustainable biofuel development in the continent.

Biofuels may be sustainable in some instances while unsustainable in others. It is therefore the responsibility of each country to carry out a proper and systematic, country-specific analysis to assess the viability of biofuels development to ensure that the economic benefits of biofuels are not given too much priority at the expense of other important values of the environment and society. Developing countries must define their own biofuels development path and develop appropriate legislation to ensure that biofuel development is sustainable and appropriate policies (criteria & indicator relevant to local situation) should be put in place to address social, environmental and economic issues. For example, biofuels can be developed in diverse land use situation. While conventional management methods (physical criteria) may be used to differentiate land uses according to physical criteria, actual land uses also changes based on changing needs as demands from society, market opportunities and ‘stakeholder’ entitlements evolve [74]. It is therefore important to consider the dynamics of land usage when assessing the environmental, economic and social impacts. Ideally, biofuel policy should manage and monitor the land use spectrum of both large- and small-scale developments in time and space, and manage the changes resulting from interactions among economic, ecological and socio-political factors to help ensure sustainable biofuel development. Appropriate policies and policy mechanisms will have to be developed to maintain and manage water resources and balance the use of land for food and biofuel crops. This requires a comprehensive survey on the potential arable land and spatial development frameworks that maintain the minimum requirements to secure the basic food supply of the population.

Lastly, as biofuels gain market share and international trading of biomass raw materials and biofuels expands, the need to ensure sustainability along the whole supply chain becomes more pressing. This includes aspects such as land use, agricultural practices, competition with food, energy efficiency and GHG emissions. The strategy to achieve sustainability includes the need for certification systems. Developing certification procedures for biomass feedstock to be used in biofuel production requires identification and assessment of existing systems followed by measures taken to improve them. The existing legal framework should be taken into consideration while learning from recent national initiatives in other countries (such as the draft biofuel sustainability ordinance passed by the German Federal Government). Certification procedures need to be applicable at both global and local levels and relate both to small farmers or foresters as well as large conglomerates.

7. Conclusions

Developing countries such as Africa need to carefully consider the benefits and detriment of biofuels, particularly in relation to the effects on food production and food prices. For sustainable biofuels production in Africa, priority should be given to strengthening local production to satisfy national need and benefits at local level while international trade should only be considered as a secondary option. If left unregulated, biofuels development will put a heavy burden on the poor since they will be based on an industrial model of agriculture that fails to ensure the equitable sharing of benefits and improve the quality of life of the rural poor. Therefore, biofuels development needs to take place in a framework of sustainable development that considers the economic, social and ecological issues. Biofuel development requires an approach that recognises the multi-functionality of agriculture and applies the principles of agro-ecology so that biofuel developments can be sustainable. There are many possibilities to integrate and synergise agricultural practices and technologies to reduce the conflict that biofuel presents in resources used for food versus fuels. This includes biofuel production that utilises wastes, is flexible in its feedstock requirements, and/or uses technology or process synergy, hybrids or feedstock fractionation to ensure affordable renewable energy access that does not compromise, but rather compliments, the food production. A model of biofuel development should therefore be based on one of industrial ecology that holistically considers the energy, products (food fuel, and others) and wastes and actively plans biofuel development for sustainability.

To ensure sustainable biofuels development in Africa that will pay due respect to gender issues, environmental and social impact assessments of proposed biofuels projects or programmes should include an evaluation of gender-differentiated impacts. Consultative processes should be designed to ensure substantial participation of women. Gender equity should be one of the principles considered in sustainability assessments.

Most of the threats related to biofuel production come from the operation of large-scale plantations using agro-business models. In order to avoid negative impacts, the interests of small landowners need to be protected by engaging them as producers and processors of biofuels as part of a larger value production and supply chain. For this, governments should develop and promote biofuels policies, regulations and programmes that take into account the needs and interests of small farmers and women in rural communities. There must also be specific policies in place before biofuels are developed or implemented and the developments need to be carefully monitored and regulated to ensure that biofuels development contribute to the Millennium Development Goals, the targets for reductions in carbon emissions and generally promote a sustainable development path. A recommendation is that there are clear policies and incentives in place that are a function of technology maturity. There is also a need to develop a comprehensive biofuels programme (policy formulation and promulgation) that is thoroughly debated and evaluated (by both communities and government) for value addition to the economy and that has reduced negative social environmental impacts.

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